Chemistry education now

Apotheker, Jan

Published in:
L'Actualité Chimique

Publication date:
2019

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The turning of the century showed the need for a change in science education. On the one hand the number of students in science dropped, while on the other hand the importance of future scientists became more and more obvious. Both the Lund Declaration [1], as well as the United Nations (UN) sustainable development goals [2] state the need for scientists in order to tackle the challenges the world society faces.

Like physics and to a lesser extent biology, chemistry education has gone through a difficult period at the beginning of the century. In the ROSE ("Relevance of Science Education") report [3], students from about forty countries were interviewed about their attitudes towards science and science education. Students do seem to have a positive attitude towards science. They feel science makes their live easier and more comfortable, and will make work more interesting. There is some skepticism, especially among girls about the possible harmful effects of science and technology. Science education though is another matter. Students indicate that school science is less interesting than other subjects, most important school science has not shown the importance of science for society. Another important statement from the report was that science did not introduce new exciting job opportunities.

It was clear that the science curriculum, including chemistry, was not very up to date. The things students learned – equilibrium, acid-base theory, redox reactions, organic chemistry for example – had little or no relationship with current research at universities, or main problems in society. Other factors that had a negative influence were things like teacher domination, competitive assessment, traditional teaching methods, poor learning environment.

In order to let students appreciate science more, science-education had to change.

A molecular science

Since 2000, chemistry education has undergone quite some changes. In chemistry education the focus changed from the study of chemical reactions towards the study of chemistry as a molecular science. Focusing not only on molecular processes, but also on the relation between (molecular) structure and properties. One of the main themes became the relationship between macroscopical phenomena and changes at the molecular level. With the emergence of nanotechnology, this intermediate size was studied as well.

The main challenge was how to make science education more relevant for students. Two aspects played a major role in the solutions that were ultimately found: the first was linking chemistry to the everyday world; the second showcasing chemistry research in education, to demonstrate how exciting research can be.

The use of contexts was one of the solutions that was tried out, and was successful in motivating students. Instead of just teaching certain concepts, a context is introduced and discussed before relating the concepts to the context. A context can be a lot of things. Normally it would be a societal situation, in which students are discussing, for example detergents, and learn about the molecular background of detergents. Cosmetics are another example that was often used as a context to introduce the difference between hydrophobic and hydrophilic substances.

In a recent example, students are confronted with the question: "Why does a baby not drink milk from a carton?" [4] (*figure 1*).

Figure 1 - This is milk as well, isn't it?

Since milk is basically built up as an emulsion of fats, proteins and carbohydrates, this leads to the introduction of the molecular properties of proteins, carbohydrates as well as fats. These substances can be studied in some detail, in which the chemistry of these compounds is introduced and learned by the students.

Going into more societal issues, it appears that after about one month the percentage of women still breastfeeding their babies drops to about 57%. The World Health Organization (WHO) advises complete breastfeeding until six months, bus as maternity leave ends after four weeks, quite a few women stop breastfeeding or mix it with formula milk.

The introduction of formula milk leads to questions about the composition and production of formula milk. How do you get from *figure 2a* to *figure 2b*?

Apart from discussing and learning about the production process of formula milk in a factory, students learn about chemical technology in general. This case leads to recent research done at the University of Groningen about the role of human oligosaccharides in breastmilk (HMOS). These HMOS

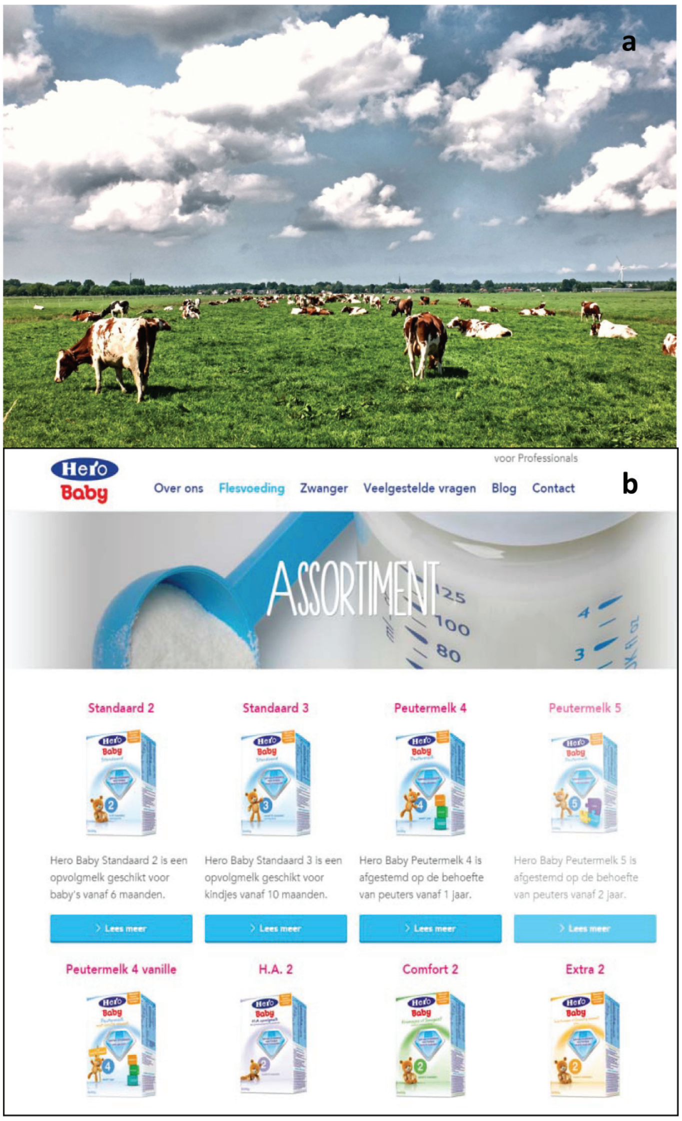

Figure 2 - From Dutch cows (a) to formula milk (b).

play a role in the development of gut bacteria in the baby (*figure 3*).

The research group in Groningen found that galacto-oligosaccharides (GOS) can have the same effect. Since then these GOS have been added to formula milk. This gave the opportunity to introduce both microbiology as well as the introduction of the intestinal system in humans. This includes the use of metagenomics for the identification of the gut bacteria.

It demonstrated to the students the role of recent research in a societal very relevant aspect of their lives. Most of the students have been breast fed, but have also had formula milk.

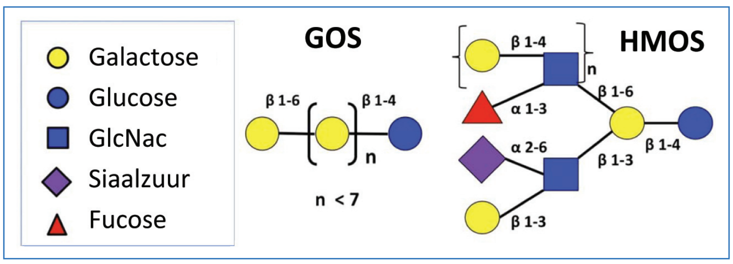

Figure 3 - Possible structures for human milk oligosaccharides (HMOS) and galacto-oligosaccharides (GOS).

This combination of the students own experiences and the underlying molecular explanations are a main feature of modern chemistry education. It motivates students, but also showcases relevant recent research taking place at the university (the educational material presented above can be found at [5]).

Context and sustainable goals

Other research has been done to improve science education. Science education in early stages can become highly relevant for students, when it can be linked with sustainable development [6]. When students can see the role they themselves can play in sustainable development, now and in the future, they will be more motivated to understand the need for science.

Linking science education to the UN development goals for example is relatively easy. Goal 6 about clean water and sanitation for example can be used at the start of chemistry education. Separation methods like filtration, absorption as well as distillation are often introduced early on in chemistry education, in order to develop the concept of a pure substance. The preparation of drinking water is a perfect example and may lead to student work as illustrated in *figure 4*.

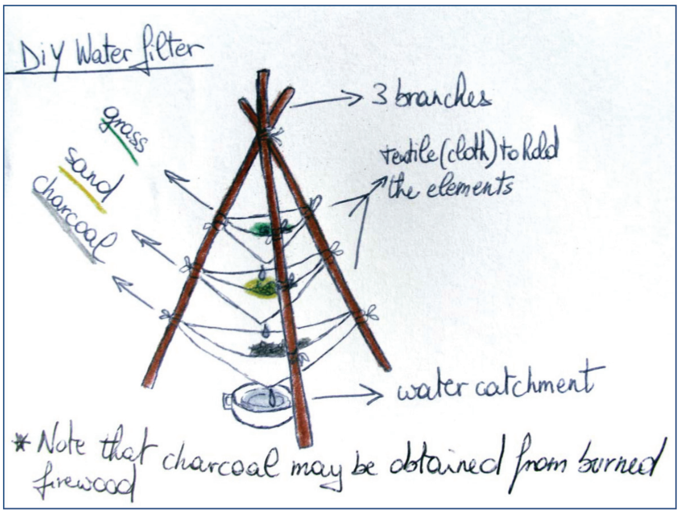

Figure 4 - Water purification (source Wikipedia).

Recently a discussion started about the central role of chemistry in relation with sustainability, as well as its relationship with other natural sciences. Chemistry is linking more and more with other natural sciences in research. The molecular aspects in astronomy, physics and biology lead to combined research groups, in which chemistry is a linking pin. This leads to all sorts of university masters in which different sciences are mixed.

Systems play a vital role in the study of environmental issues, and require a more holistic view of a problem, in which chemistry plays a role. As can be seen in the example of breast feeding discussed above, there are interfaces between chemistry and engineering, chemistry and biology, as well chemistry and sociology. While in biology systems are part of the normal curriculum, systems are not part of the normal chemistry curriculum.

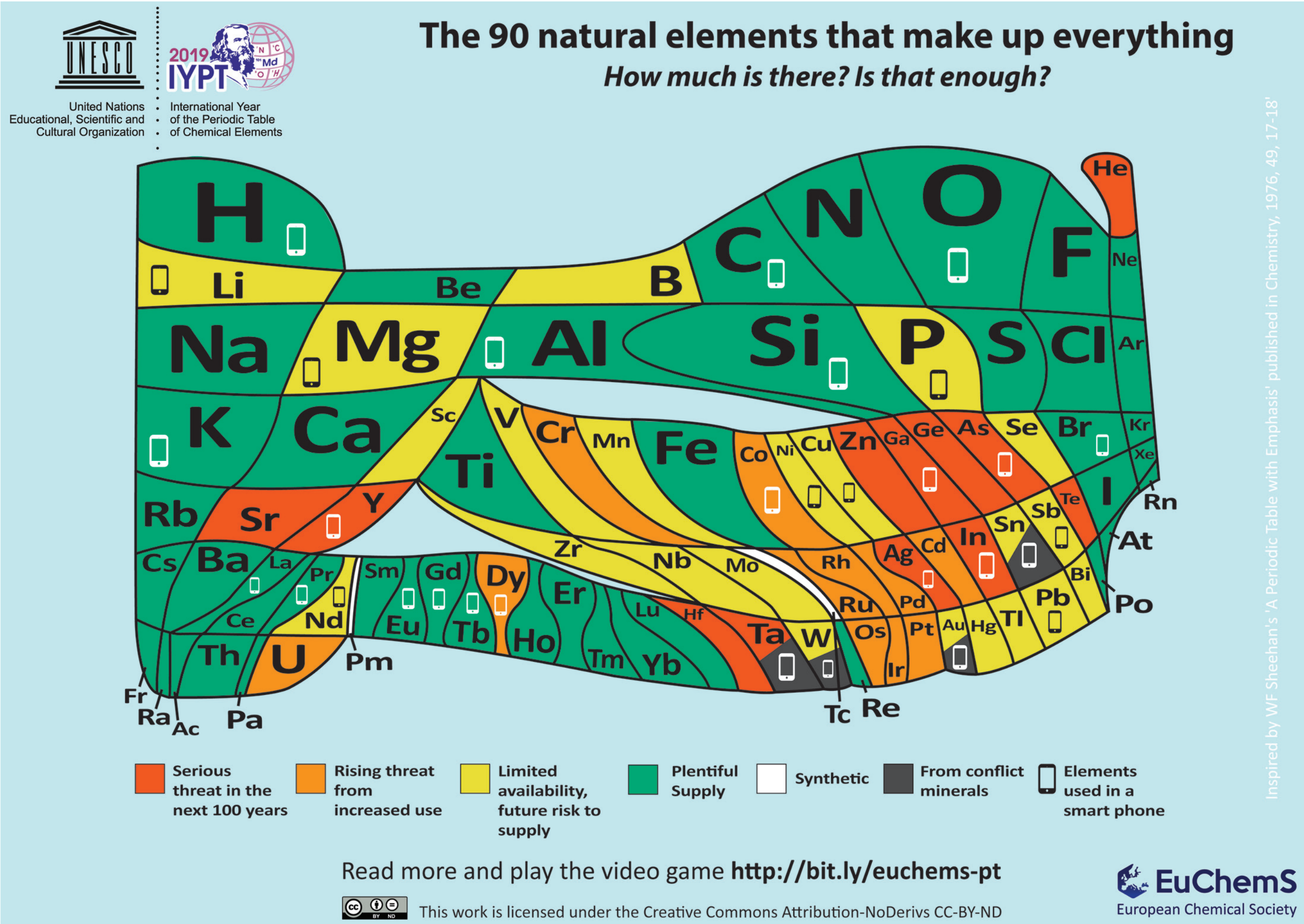

Figure 5 - Periodic table showing the availability of elements (credit: EuChemS/CC-BY-ND).

This has led to a discussion about the introduction of systems thinking in chemistry education.

The introduction of systems offers a way for studying concepts like life cycle analysis, cradle to cradle design, which are important if we want to discuss the future use of base materials. The publication of a periodic table by EuChemS to highlight 2019 as the International Year of the Periodic Table is a nice example of the problems associated with the availability of elements (*figure 5*).

Chemistry education continues to evolve around the world, and in the past twenty years has managed to change the negative trend in the appreciation of chemistry as a science [7].

[1] European Commission, The Lund Declaration **2015**, www.regjeringen.no/contentassets/27b6beaf195a42bea42a0c3001b431cb/lund_declaration2015v4.pdf

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[3] Sjøberg S., Schreiner C., The ROSE project: an overview and key findings, **2010**, www.roseproject.no/network/countries/norway/eng/nor-Sjoberg-Schreiner-overview-2010.pdf

[4] Apotheker J.H., Teuling E., Carbohydrates in breastmilk, IPN, Kiel, **2017**.

[5] www.irresistible-project.eu/index.php/en/resources/teaching-modules

[6] Eilks I., Hofstein A., Combining the question of the relevance of science education with the idea of education for sustainable development, In *Science Education Research and Education for Sustainable Development*, I. Eilks, S. Markic, B. Ralle (eds), Shaker, Aachen, **2014**, p. 3-14.

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Jan APOTHEKER,

Chair Committee on Chemistry Education IUPAC, Faculty of Science and Engineering, University of Groningen (The Netherlands).

*j.h.apotheker@rug.nl